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The Advanced Communications Technology Satellite (ACTS) is an experimental telecommunications satellite which is being built for NASA and is scheduled to be launched in July 1993. The satellite will act as a test bed for high gain hopping spot beams, on-board processing, and Ka-band technologies. The incorporation of these technologies provides it with many different capabilities, including the ability to transmit digital data with a data latency of less than one second at rates up to hundreds of megabits per second. NASA has developed a user-based experiments program to demonstrate the capabilities of the satellite. Experimenters have the opportunity to evaluate the potential of ACTS technologies to meet their communications needs.

The U.S. Army Topographic Engineering Center (TEC) will be using the ACTS for transmitting Differential Global Positioning System (DGPS) data to test for its use with meter and decimeter level applications in real time. The ACTS satellite communications has the capacity to transmit additional data, such as digital mapping data, with DGPS data in real time.

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BIOGRAPHY

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Ms. Sally L. Frodge researches and develops applications of GPS and DGPS for implementation within the U.S. Army Corps of Engineers. Currently she is also Principal Investigator for the real-time on-the-fly decimeter system development. She is a Computer Scientist at TEC.

Mr. Mark Plecity is the Experimenter Development Manager in the Advanced Communications Technology Satellite (ACTS) Experiments Office. His principal areas of focus are DoD organizations, academic institutions, and mobile users.

Mr. Roger Dendy is a Communications Engineer with Analex Corp. where he has been supporting the ACTS Experiments Office at the NASA Lewis Research Center since August 1991.

ABSTRACT

The Advanced Communications Technology Satellite (ACTS) is an experimental telecommunications satellite which is being built for NASA and is scheduled to be launched in July 1993. The satellite will act as a test bed for high gain hopping spot beams, on-board processing, and Ka-band technologies. The incorporation of these technologies provides it with many different capabilities, including the ability to transmit digital data with a data latency of less than one second at rates up to hundreds of megabits per second. NASA has developed a user-based experiments program to demonstrate the capabilities of the satellite. Experimenters have the opportunity to evaluate the potential of ACTS technologies to meet their communications needs.

The U.S. Army Topographic Engineering Center (TEC) will be using the ACTS for transmitting Differential Global Positioning System (DGPS) data to test for its use with meter and decimeter level applications in real time. The ACTS satellite communications has the capacity to transmit additional data, such as digital mapping data, with DGPS data in real time.

This paper describes the advanced technologies of ACTS, and the potential benefits of these technologies for future satellite communications. It describes the various earth station types that have been developed to support experimentation with ACTS. This paper also describes the ACTS Experiments Program and the various experiments and experimenters participating in the program to use the ACTS. Specifically, the three phase experiment with DGPS will be discussed. Phase one is to conduct the experiment over a baseline of 320 km in static mode; phase two is to utilize the sled track at the Holloman Air Force Base, New Mexico to conduct a controlled kinematic test; and phase three will be a kinematic test on board a mobile platform.

THE ADVANCED COMMUNICATION TECHNOLOGY SATELLITE

The Advanced Communications Technology Satellite (ACTS) is an experimental program intended to develop and demonstrate the next generation of satellite communications technology, in order to maintain U.S. preeminence in the satellite communications industry. The ACTS is currently completing final testing and is scheduled to be launched aboard the space shuttle in July 1993.

The goal of ACTS is not just to develop new technology, but to transfer that technology to the U.S.

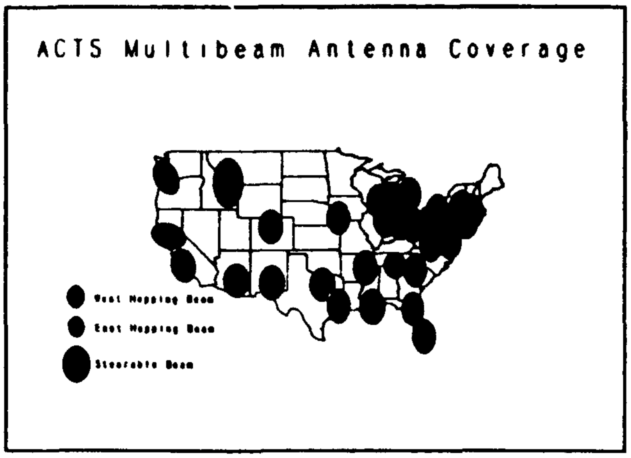

Figure 2 ACTS Spot Pattern

that the satellite acts as a *regenerative* repeater, isolating the uplink from the downlink. Thus a degradation on the uplink may appear as bit errors in the satellite and be retransmitted, but it does not appear as a weak signal-to-noise ratio which can be further degraded on the downlink. On a link in which uplink and downlink carrier to noise ratios are equal, for example, this results in a 3 dB improvement in the overall link.[4]

On-board switching. The use of spot beams allows the satellite to differentiate among earth stations by location, in effect a physical address. This allows the satellite to isolate messages intended for users in one location from users in another location. In order to take advantage of this isolation, the ACTS baseband processor was designed to include on-board switching. The baseband processor demodulates the uplink signal, reads its address information on a channel by channel basis, routes it to the appropriate downlink beam, and transmits the signal down. The ACTS baseband processor, in conjunction with the antenna scanning beams, is functionally equivalent to an Electronic Switching System 4 (4ESS) switch, the current generation of commonly used telephone switching equipment.[5]

This capability effectively eliminates the need for satellite hub stations as they currently exist in many networks. In current satellite networks, medium sized earth stations (5-8 m) can communicate directly with each other. But in order to use VSAT's (<2 m), the network must be configured as a star, or hub-and-spoke, with a large earth station (11-13 m) at the hub, as shown in **Figure 3**. In order for a VSAT to communicate with another VSAT, the signal would have to go to the hub first, be regenerated, and then be retransmitted through the satellite to the receiving VSAT. This creates a roughly 1 sec round-trip delay, making current VSAT's unattractive for voice or latency-sensitive applications, such as Differential Global Positioning System (DGPS) applications seeking accuracies of 3 meters or less.

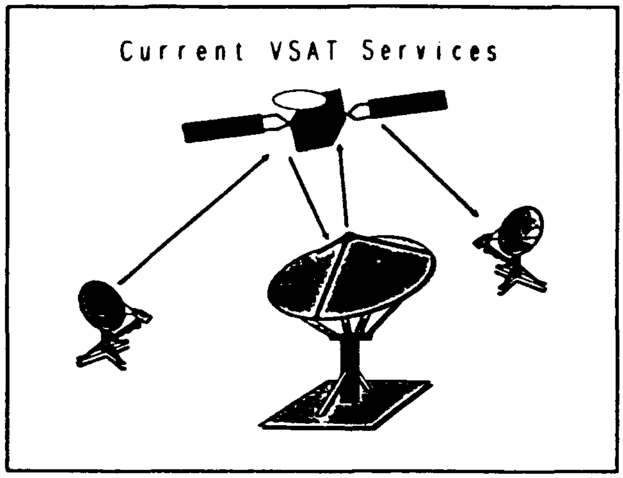

Figure 3 Star Network Configuration

With the ACTS switching capability, the hub is on board the satellite, and the signal is regenerated there. This allows any VSAT to communicate directly to any other with only one transmission through the satellite, constituting a full mesh network among all ground terminals.

Time Division Multiple Access (TDMA). The use of spot beams with on-board processing allows ACTS to serve all users on the same frequency using a TDMA scheme, in which each user is assigned a time slot for the uplink and a time slot for the downlink, and the satellite moves from spot to spot and from user to user on both uplink and downlink. The use of TDMA allows single channel per carrier (SCPC) operation, avoiding the 4-5 dB backoff required to prevent intermodulation in Frequency Division Multiple Access (FDMA) schemes.[6]

Adaptive FEC. One obstacle to the implementation of Ka-band communications systems has been the high susceptibility to fading in moist atmospheric conditions of the troposphere. In order to compensate for this tendency to fade, ACTS implements FEC coding on an as-needed basis. The FEC coding can be implemented dynamically, transparent to the user equipment, and because of the spot beams can be employed only in those geographic regions where it is required. In addition, because of the on-board processing capability, FEC coding can be invoked independently for the uplink and the downlink.

High Data Rate (HDR). The ACTS HDR earth station is a 3.4 m dish antenna that provides a 622 Mbps communication link via ACTS. The HDR earth station uses the Microwave Switch Matrix (MSM) mode from ACTS to support a high information rate. The HDR earth station is designed for large volume transfers of data, such as databases or medical images, or providing supercomputer connectivity. The HDR terminal is designed to be portable in order to maximize the number of experimenters who have the opportunity to perform high data rate experiments. The HDR terminal will demonstrate the ACTS capability to provide service to remote users who require access to supercomputers but do not have the telecommunications infrastructure required to support this level of connectivity. The HDR earth station is designed to operate using the SONET standard optical interfaces OC-3 and OC-12.

ACTS Mobile Terminal (AMT). The AMT is a fully mobile satellite terminal which will provide voice and data communications to a user while on the move. The AMT experiments will be conducted in two phases using two different antenna configurations. The first is a small 5 inch elliptical reflector which is mechanically rotated to track the satellite as the vehicle moves. After the first phase of experiments, the test vehicle will be refitted with a low-profile, mechanically steered phased array antenna. The experiments performed with the AMT will characterize the mobile channel at Ka-band, and develop the technologies needed to provide a mobile Ka-band satellite communications system.

Ultra Small Aperture Terminal (USAT). The USAT earth station has a small 12 inch dish which supports low data rate (9.6 Kbps) communications. The USAT earth station is designed to provide remote locations with a method of updating information. The major design goals for this system are that it be low cost and deployable to very remote locations. For example, the major sponsor of this earth station development is Southern California Edison who intends to demonstrate remote monitoring of the power distribution network. This type of data acquisition network is ideal for users who require a small amount of information from numerous sites to be updated on a regular basis.

Aeronautical. The Aeronautical terminal is being developed as an effort to provide aeronautical communications using an electronically steerable Microwave Monolithic Integrated Circuit (MMIC) antenna. The antenna that will be used is a 32 element array that measures 2.5" by 1.25". This small 30 GHz array will be combined with a 20 GHz phased array antenna developed for the Air Force MILSTAR Office. These two antennas will support low data (4.8 Kbps) rate aeronautical communications. The aeronautical terminal is designed as a proof-of-concept terminal that validates the use of MMIC arrays to provide Ka-band communications links.

As a follow-on investigation, the terminal will be refitted with the elliptical reflector from the AMT and a large power amplifier, which together will supply enough gain to support data rates of up to 384 Kbps, making possible mobile slow scan video transmissions or multichannel voice transmissions from aircraft.

A DIFFERENTIAL GLOBAL POSITIONING SYSTEM (DGPS) USING THE ACTS

Telemetry Requirements of a DGPS. When selecting a telemetry link for a DGPS, a compromise is made between cost, range of the telemetry link, message update rate, and ease of implementation. The message update rate is a product of several characteristics: data rate, data latency, mode of operation (full duplex, one-way simplex, etc.), error correction, and any other data processing that may take place. The message update rate is of primary importance since it is directly related to the expected positional accuracy of DGPS. Since GPS corrections lose their validity with time, users interested in high accuracy positioning and navigation should have a telemetry system with high update rates.

Telemetry Systems for a High Accuracy DGPS. Numerous telemetry links have been recognized as capable of transmitting differential GPS data for positioning and navigation applications requiring around 5-7 meters 1DRMS. Table I provides a sample of telemetry systems and services that support those DGPS applications. For higher accuracy applications, such as 1-3 meters 1DRMS, faster message update rates are required, effectively trimming the list of available telemetry links.

Digital Radio Frequency (RF) radio links operating at Very High Frequency (VHF), 30-300 MHz, and Ultra High Frequency (UHF), 0.3-3 GHz, bands are high performers for a DGPS with data latencies of half a second or lower, high data rates up to 9600 bps, and true mobile operation. Coupled with low cost, these desirable attributes explain why digital RF radio links appear to be the most common telemetry link for DGPS. Except for applications that can tolerate short baselines, there are some drawbacks of the digital RF radios, including a mandatory requirement for a frequency allocation and a limited line-of-sight range.

Three Phase Experiment of the ACTS for a DGPS

TEC has developed a three phase experiment to ascertain the expected positional accuracies from using the ACTS for a DGPS over long baselines. The three phases will test a DGPS under static, controlled kinematic, and field kinematic conditions. The ACTS will transmit data from a dual-frequency reference receiver to a dual-frequency remote receiver with a 1 Hz message update rate (or higher) for maximum obtainable accuracies.

The performance of a DGPS using the ACTS will be evaluated from two perspectives: meter level accuracy and submeter accuracy. An evaluation for meter level accuracies will be accomplished by transmitting pseudorange corrections in the Radio Technical Commission for Maritime Services Special Committee 104 V2.0 (RTCM V2.0) format with the ACTS over long baselines (320 km and 420 km). The experiment will also test the ACTS for submeter accuracies. TEC is currently developing a prototype positioning system using DGPS that is capable of decimeter accuracy in three dimensions and in real time. This prototype system will not require static initialization and will be capable of on-the-fly integer ambiguity resolution. The GPS data required at the remote station from the reference station for the prototype system has not been determined at this time. TEC is interested in how well the ACTS can support the prototype system using long baselines.

The ACTS earth terminal arranged for the experiment will be a T1 VSAT. Although mobile terminals would be more appropriate for a kinematic DGPS, they were either too expensive or their development status was questionable when commitments to the program were made. For the kinematic phases, a digital RF radio will telemeter data from a stationary T1 VSAT to the mobile remote GPS station. Because the RF radio will increase the transmission delay a half second or less, some position degradation is expected, but it should not prevent a 1 Hz message update rate. Nevertheless, the system will be operated with and without the RF radio (while stationary) to reveal the transmission delay's impact on the positional accuracy.

Static Phase. In the static phase, a single baseline of 320 km will be established by locating a reference station in Fort Monmouth, New Jersey and a remote station in Fort Belvoir, Virginia (Figure 4). The ACTS T1 VSAT will interface with the GPS receivers and monitoring equipment at both locations through an Asynchronous-to-Synchronous converter. DGPS corrections in the RTCM V2.0 format will be sent from the reference station to the remote station using the ACTS for a meter level evaluation. No special packaging will be necessary to prepare data for the ACTS, but an asynchronous-to-synchronous conversion will be necessary to interface with the satellite terminal. A study in 1991 between TEC and the U.S. Coast Guard of the performance of a DGPS with a baseline of 519 km showed that positional accuracies to 5-7 meters 1DRMS is possible.[7] With the rapid growth in GPS receiver technology since that time, the positional accuracy of a DGPS with the ACTS is anticipated to meet 1-3 meters 1DRMS. Following the meter level evaluation, the decimeter prototype system mentioned earlier will be tested using the ACTS, and position performance will be evaluated for submeter accuracies. In addition to an overall analysis of the DGPS using the ACTS for real time positional accuracy, the ACTS itself will be evaluated for its message update rate, which will be calculated from measurements of the satellite's data latency, data rate, and Bit Error Rate.

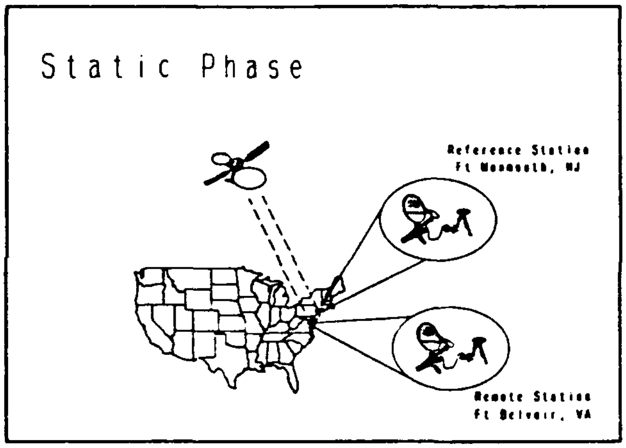

Figure 4 Static Phase

Controlled Kinematic Phase. In the controlled kinematic phase, a single baseline of 420 km will be established between a reference station in Fort Huachuca, Arizona, and a remote station at Holloman Air Force Base, New Mexico (Figure 5). The controlled kinematic environment will be produced by the High Speed Test Track at Holloman Air Force Base. Designed to simulate portions of flight trajectories for aerospace vehicles, the test track is a straight line path over 10 miles in length. Track sleds can be moved along the track with their positions accurately measured within 0.0025 feet and their velocity accurately measured within 0.001 feet/second. The equipment configuration will be identical to the static phase except for the presence of the digital RF radio link between a T1 VSAT next to the track and the mobile GPS station on the track. Position and velocity

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